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STATIC ANALYSIS AND WEIGHT REDUCTION OF ALUMINUM CASTING ALLOY CONNECTING ROD USING FINITE ELEMENT METHOD

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Original Article

ABSTRACT

The less efficiency and heavy weight are the major problem for automobile spare parts. In order to that, the material replacement is a must for automobile components for better efficiency and fuel economy. The less density and good strength material, should replace by existing material for the automotive parts like connecting rod and various parts to overcome the above problem. In this paper, the 4-stroke petrol engine connecting rod is taken into consideration for material replacement. The connecting rod is an intermediate connecting member between the piston and crankshaft, its primary function is to transmit the push and pull from the piston pin to crank pin also it's converting the reciprocating motion into rotary motion. Usually connecting is made up of low alloy steel like HSLA steel 4140. In this work, the existing connecting rod material HSLA steel 4140 can be replaced by AL S355 (Aluminum) casting alloy, because this AL S355 (Aluminum) casting alloy having very good strength among the aluminum alloy group of materials and very less density when compared to steel.

The FEA model can be created using PRO-E 4.0 software and it's imported to FEA code ANSYS 15.0 software. The deflection, stress, strain is obtained from FEA software. The factor of safety, weight and stiffness are numerically calculated and verified with FEA value. Finally concluded that AL S355 casting alloy material is suitable for connecting rod also it gives 34.3% weight reduction and 88% more stiffness than HSLA steel4140.

***KEYWORDS**: Connecting Rod, Finite Element Analysis, HSLA Steel 4140, ALS355 Casting Alloy, Factor of Safety, ANSYS 15.0 & PRO-E 4.0.*

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INTRODUCTION

The connecting rod is a very important intermediate element in the I.C engine, steam engine, reciprocating compressors, pumps, power hammers and beam engine, etc. Which is used to convert the rotary motion into reciprocating motion while the engine is running? The piston rod connected with the piston of an engine and transmits gas pressure developed by the fuel or steam to the crankshaft through connecting rod. It's a part of the engine, which is subjected to millions of repetitive cyclic loadings because of alternative tensile and compressive forces.

The selection of materials for connecting rod has become an essential task for the above-mentioned applications. In the view of open to all types of materials, that material should be less density, high strength, also it gives minimum stress, strain and deflection when it's in running condition. Moreover,that material should give a better factor of safety, high fatigue strength and weight reduction. Normally the connecting rod made up of carbon

steel and low alloy steel like HSLA4140 steel (1) etc. But these types of steel have very high density and low strength when compared to aluminum alloy materials. Among the aluminum alloy group of materials AL S355 casting alloy (1) have good strength and better weight ratio. The aluminum alloy materials will give a better weight reduction for automotive applications, nearly 1/3 of weight will be reduced when compared to steel (15).

LITERATURE REVIEW

- Anusha.B. et al (2013) [8] had done HERO HONDA spender connecting rod case study. In her study, the big end was fixed and 3.15 Mpa pressure load applied at the small end. As a result piston end was identified it's under maximum stress.
- B.Kuldeep et al (2013) [6] had done an FEA analysis for replacing connecting rod material by Aluminum based composite material, reinforced contained with silicon carbide and fly ash, as a result, weight reduction was achieved with better stiffness and optimized connecting rod was 43.48% lighter than existing designs.
- H.B.Ramani et al (2014) [13] had done in a static analysis for finding stress, strain rate and shape optimization for connecting rod, as a result, weight reduction is possible with low stress and an optimized connecting rod was 15% lighter than existing designs.
- Mohamed Abdu SalamHussin et al (2014) [12] had modeled two-wheeler connecting rod in solid works and analyzed using FEA code ANSYS software. He had compared forged steel and aluminum, has von misses stress, strain, deformation, factor of safety and weight reduction analysis using ANSYS software. Finally concluded that Aluminum alloy is better than that forged steel.
- P.D.Toliya et al (2013) [11] had done an analysis of aluminum 6351 connecting rods. Had applied the tensile and compressive load at the crank end and piston end of connecting rod, as a result, the stress value of the middle of the shank was very low when compared to another part of connecting rod.
- Priyakgrounder Suresh et al (2014) [4] had studied optimization of intervening variables in micro EDM of SS316L using a genetic algorithm and response surface methodology, the optimization model was developed by simultaneously considering the maximization of MRR and minimization or TWR, which highly uses full for real-life applications.
- Raj.B.Soni et al (2016) [14] had done the material comparison for four-stroke single cylinder 100cc bike connecting rod. The existing connecting rod made up of AISI 8620 steel that can be replaced by Aluminum alloy 8620, had done a theoretical and analytical analysis of Factor of safety, fatigue strength for 10^7cycles and weight reduction in both the materials, concluded that Aluminum alloy is the best choice and it gave 22% weight reduction.
- S.Chorghe et al (2014) [10] had compared steel and aluminum materials for connecting rod, he had been doing performance, shape, weight optimization of both the materials, finally concluded that Aluminum is the best choice for connecting rod because of less weight and more yield strength.
- Saravanan A et al (2017) [2] had investigated the maximum pressure obtained a ratio of the air-fuel mixture in the lorry diesel tank using the numerical and analytical method. For pressure and crash analysis, took the lorry

diesel tank material was HSLA Steel 4140. As a result, 95% fuel and 5% air are the dangerous air-fuel mixture ratio.

- Sarkate T S et al (2014) [10] had done an analysis of aluminum LM6 and structural steel for connecting rod. Had applied the tensile and compressive load at the crank end and piston end of connecting rod for both the materials, as a result, the stress and strength value was better for Aluminum alloy also less weight.
- Suresh P et al (2014) [3] had a study of micro EDM parameters of stainless steel 316L, the material removal rate of steel 316L using300µm tungsten electrode in micro EDM and deriving a mathematical model using surface methodology.

FORCE ACTING ON A CONNECTING ROD

A connecting rod is subjected to following forces:

- Force due to gas pressure and inertia of reciprocating parts
- Inertia bending forces
- Force due to the friction of the piston rings and of the piston
- Force due to the friction of the piston pin bearing and the crank pin bearing

MATERIALS AND PROPERTIES

The material properties of both the materials are tabulated in Table.1 for this analytical and numerical analysis.

Table 1: Material Properties of HSLA Steel 4140 and AL S355 Casting Alloy

S.NO	Properties	UNIT	HSLA Steel 4140	AL S355 Casting Alloy
1	Density	Kg/m^3	7850	2700
2	Modulus of Elasticity(E)	Gpa	210	70
3	Poisson's ratio	-	0.30	0.33
4	Tensile yield strength	Mpa	415	265
5	Tensile ultimate strength	Mpa	645	470

BOUNDARY CONDITION

The connecting rod tends to tensile and compressive forces so that the following boundary conditions, taken for static analysis it's shown in Figure.4 to Figure.9.

- Crank end tensile load
- Crank end compressive load

ANALYTICAL ANALYSIS OF CONNECTING ROD USING FEM

The analytical analysis of connecting rod can be carried out using FEA software ANSYS 15.0. The FEA model of connecting rod can be drawn using PRO-E Wildfire 4 software and it's imported to ANSYS 15.0.

FEA Model of Connecting Rod

The FEA model of connecting rod can be drawn in PRO-E Wildfire 4 software as shown in Figure.1.

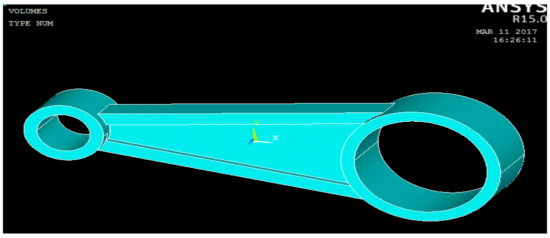

Figure 1: FEA Model of Connecting Rod

Meshing View

The meshed view model of connecting rod as shown in Figure.2.

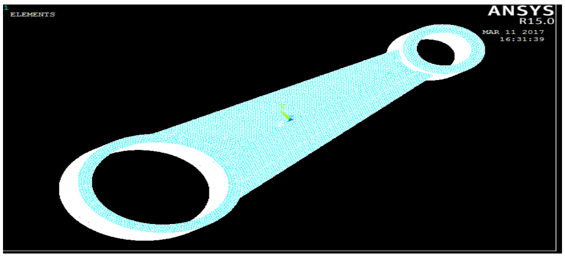

Figure 2: FEA Meshed View of Connecting Rod

Boundary Condition

The big end of connecting rod is fixed and the load applied at the small end, this boundary condition as shown in Figure.3.

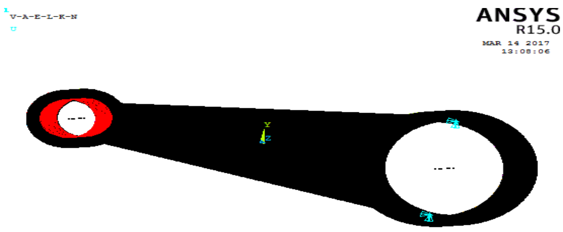

Figure 3: Boundary Condition

DEFLECTION RESULT

The deflection value of steel and aluminum alloy obtained from FEA code ANSYS 15.0 software as shown in Figure.4 and Figure.5.

HSLA Steel 4140

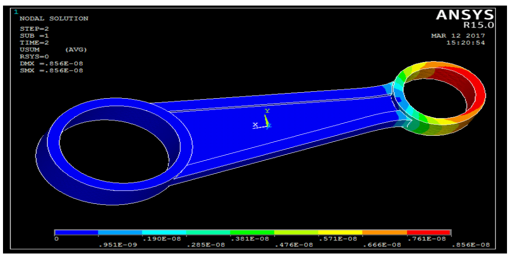

Figure 4: Deflection for HSLA Steel 4140

AL S355 Casting Alloy

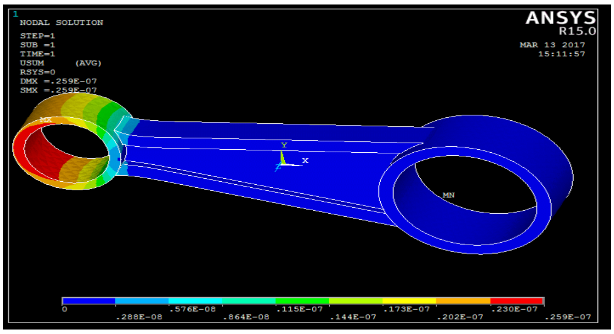

Figure 5: Deflection of AL S355 Casting Alloy

Stress Value from ANSYS 15.0

The stress value of steel and aluminum alloy obtained from FEA code ANSYS 15.0 software as shown in Figure.6 and Figure.7.

HSLA Steel 4140

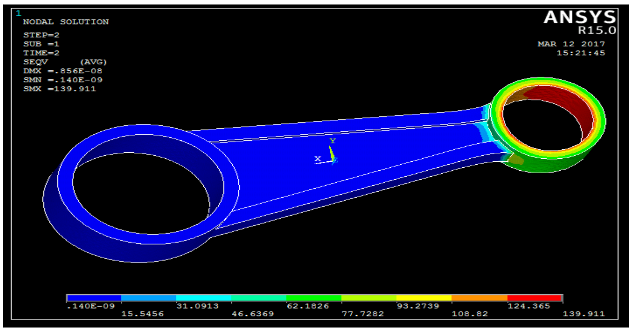

Figure 6: Stress Analysis for HSLA Steel 4140

AL S355 Casting Alloy

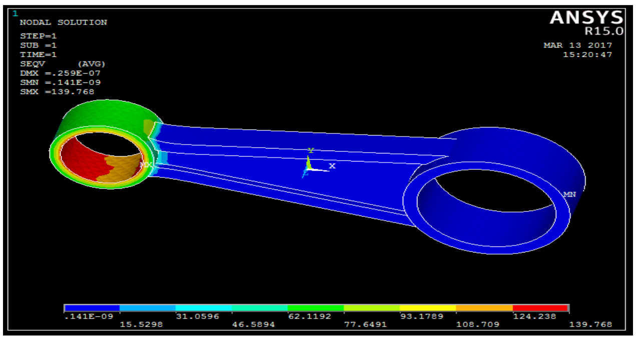

Figure: 7 Stress Analysis for AL S355 Casting Alloy

Strain Values from ANSYS 15.0

The strain value of steel and aluminum alloy obtained from FEA code ANSYS 15.0 software as shown in Figure.8 and Figure.9.

HSLA Steel 4140

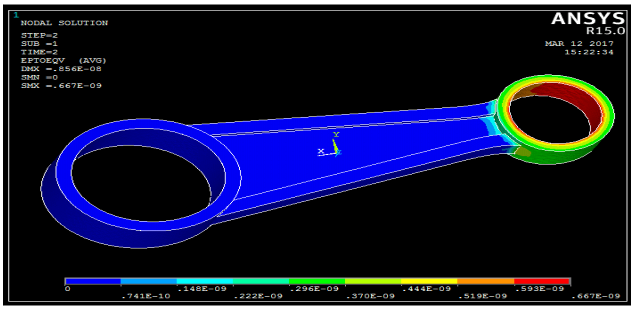

Figure 8: Strain Analysis for HSLA Steel 4140

AL S355 Casting Alloy

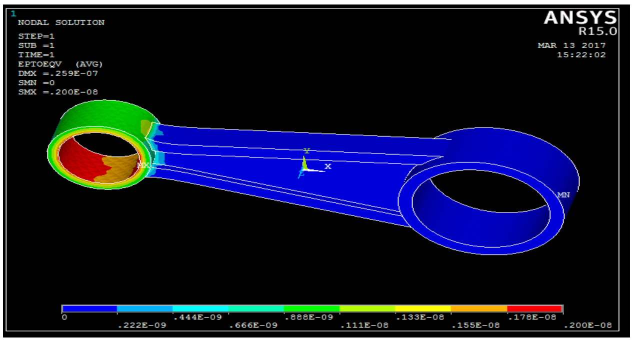

Figure 9: Strain Analysis for AL S355 Casting Alloy

THE RESULT (ANALYTICAL)

The stress, strain and deflection values are obtained from FEA code ANSYS 15.0 software and tabulated as shown in table.2.

Table 2: Analytical Result for HSLA Steel 4140 and AL S355 Casting Alloy

S.NO	Material	Tensile			Compressive		
		D.V.S. (m)	V.Stress (N/m^2)	V.Strain (m/m)	D.V.S. (m)	V.Stress (N/m^2)	V.Strain (m/m)
1	HSLA 4140	0.856 e^{-08}	139.911	0.667 e^{-09}	0.856 e^{-08}	139.911	0.667 e^{-09}
2	AL S355	0.259 e^{-07}	139.768	0.200 e^{-08}	0.259 e^{-07}	139.768	0.200 e^{-08}

D.V.S- Displacement vector sum, V.Stress- Von misses stress and V.Strain- Von misses strain

The von misses stress values are plotted on a curve as shown in Figure.10

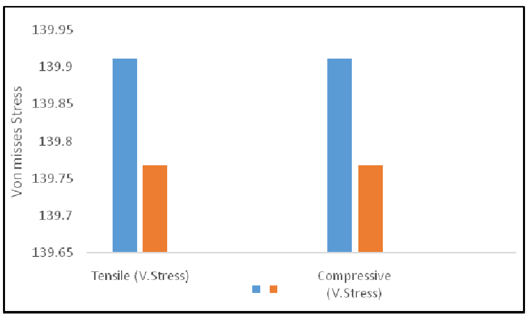

Figure 10: Von-Misses Stress Curve

Numerical Analysis of Factor of Safety

Various stresses are shown in Figures Minimum stress $\sigma_{min,}$maximum stress σ_{max}, mean stress $\sigma_{m,}$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

$$\sigma_v = \frac{\sigma_{max} - \sigma_{min}}{2}$$

$$R = \frac{\sigma_{min}}{\sigma_{max}}$$

R- Stress ratio

Calculation by a factor of safety for connecting the rod

$$\frac{1}{f.s} = \frac{\sigma_m}{\sigma_u} + \frac{\sigma_v}{\sigma_e}$$

HSLA Steel 4140

$$\sigma_{max} = 139.911 MPa$$
$$\sigma_{min} = 0.0140 MPa$$
$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$
$$\sigma_m = \frac{139.911 + 0.0140}{2}$$
$$\sigma_m = 69.959 MPa$$
$$\sigma_v = \frac{\sigma_{max} - \sigma_{min}}{2}$$
$$\sigma_v = \frac{139.911 - 0.0140}{2}$$
$$\sigma_v = 69.9485 MPa$$

$$\sigma_u = 645 MPa$$
$$\sigma_e = 0.5 x \sigma_u$$
$$\sigma_e = 0.5 x 645$$
$$\sigma_e = 322.5 MPa$$
$$now$$
$$\frac{1}{f.s} = \frac{69.959}{645} + \frac{69.9485}{322.5}$$
$$f.s = 0.32$$

AL S355 Casting Alloy

$$\sigma_{\max} = 139.768$$
$$\sigma_{\min} = 0.0149$$
$$\sigma_m = \frac{139.768 + 0.0149}{2}$$
$$\sigma_m = 69.89 MPa$$
$$\sigma_v = \frac{139.768 - 0.0149}{2}$$
$$\sigma_v = 69.89 MPa$$
$$Now$$
$$\sigma_u = 470 MPa$$
$$\sigma_e = 0.4 x \sigma_u$$

$$Now$$
$$\sigma_u = 470 MPa$$
$$\sigma_e = 0.4 x \sigma_u$$
$$\sigma_e = 188 Mpa$$

Now, Factor of safety (f.s)

$$\frac{1}{f.s} = \frac{69.89}{470} + \frac{69.87}{188}$$
$$f.s = 0.5203$$

Analytical Analysis for Factor of Safety Using FEM

The factor of safety analysis can be carried out using FEA code Ansys 15.0 software, it's given in the Figure.11 and Figure.12.

HSLA Steel 4140

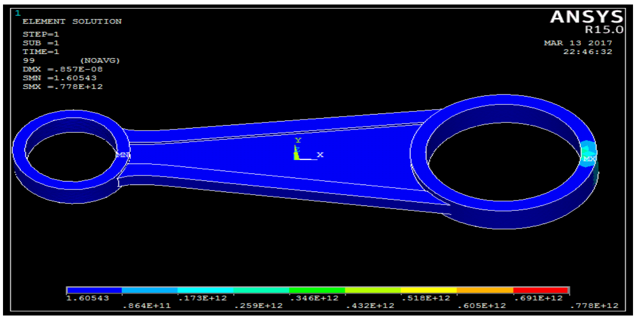

Figure 11: Analysis of Factor of Safety for HSLA Steel 4140

AL S355 Casting alloy

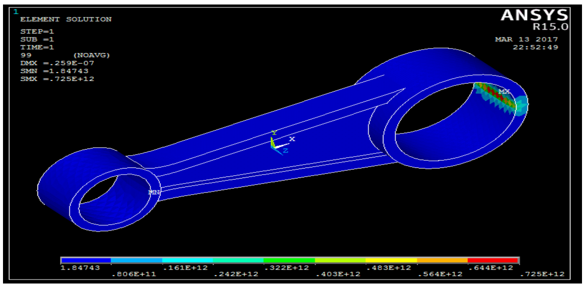

Figure 12: Analysis of Factor of Safety for AL S355 Casting Alloy

Results for Factor of Safety (F.O.S) -Numerical and Analytical Value

The Analytical and Numerical values for HSLA Steel 4140 and AL S355casting alloy for the Factor of Safety Analysis are taken and tabulated in table.3.

Table 3: Analytical and Numerical Result for HSLA Steel-F.O.S

S.No	Material	Factor of Safety			
		Numerical Value		Analytical Value	
		Tensile	Compressive	Tensile	Compressive
1	HSLA Steel 4140	0.32	0.32	1.605	1.605
2	AL S355 Casting alloy	0.52	0.52	1.84	1.84

The factor of safety values is taken and plotted on the curve as shown in Figure.13

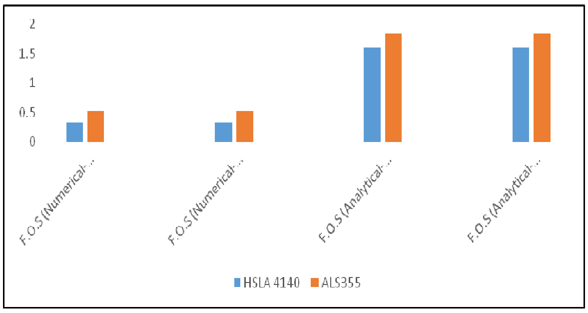

Figure 13: The factor of Safety curve

MODEL CALCULATION FOR WEIGHT AND STIFFNESS (NUMERICAL)

HSLA steel 4140

Weight of connecting rod = Density x Volume

Density of HSLA steel = 7850 Kg/m^3

Volume of connecting rod = .000092419m^3 (constant value for steel)

Weight of connecting rod = 7850 x.000092419 = 0.7254 Kg

Weight of connecting rod = 7.11 N

Stiffness of connecting rod = Weight/ Deformation= 7.11 / 0.0000856

Stiffness of connecting rod = 83060.9 N/mm

AL S355 Casting alloy

Weight of connecting rod = Density x Volume

Density of AL S355 Casting alloy = 2700 Kg/m^3

Volume of connecting rod = .000060477 m^3[constant value for Aluminum-(12)]

Weight of connecting rod = 2700 x.000060477 = 0.249 Kg

Weight of connecting rod = 2.44 N

Stiffness of connecting rod = Weight/ Deformation

= 2.44 / 0.0000259

Stiffness of connecting rod = 94208.49N/mm

Results (Numerical Value with Analytical Value)

The Numerical values for HSLA Steel 4140 and AL S355casting alloy for weight and stiffness are taken and tabulated in table.4.

Table 4: Numerical Result for Weight and Stiffness

S.No	Material	Weight (N)	Stiffness (N/mm)
1	HSLA Steel 4140	7.11	83060.9
2	AL S355 Casting alloy	2.44	94208.49

The weight values are plotted in the curve as shown in Figure.14

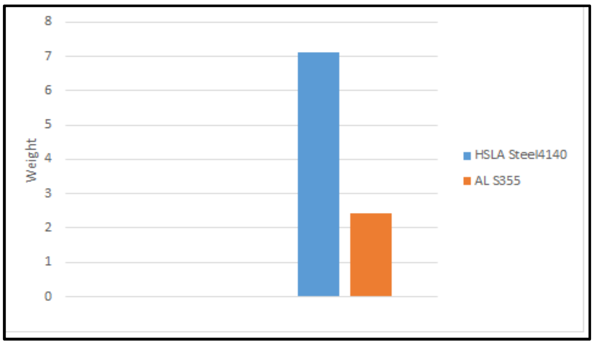

Figure 14: Weight Curve

The stiffness values are plotted in the curve as shown in Figure.15

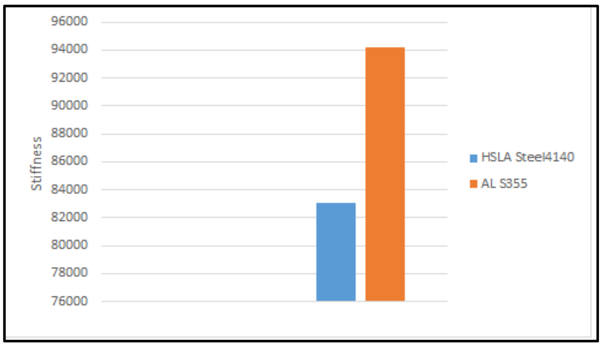

Figure 15 Stiffness Curve

CONCLUSIONS

The following results can be investigated from the above analysis

- The Analytical value of stress and strain and deflection values of AL S355 casting alloy (Aluminum alloy) is lower than that of HSLA Steel 4140. From that it can be concluded, the AL S355 (Aluminum alloy) has ultimate strength is high.
- As per the Numerical value of factor of safety and Analytical value of factor safety are same. From that, the factor of safety of AL S355 (Aluminum alloy) is better than that of HSLA Steel 4140.
- From the Numerical Analysis for weight and stiffness, the AL S355 casting alloy (Aluminum alloy) has very less weight and very good stiffness than that of HSLA Steel 4140.
- From that Numerical analysis, if connecting rod made up of AL S355 (Aluminum alloy) the weight will be reduced by 34.3% and stiffness will be increased by 88% when compared to HSLA Steel 4140.
- From that above Numerical and Analytical (FEA) analysis concluded that the
- AL S355 casting alloy (Aluminum alloy) is suitable for connecting rod applications.

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